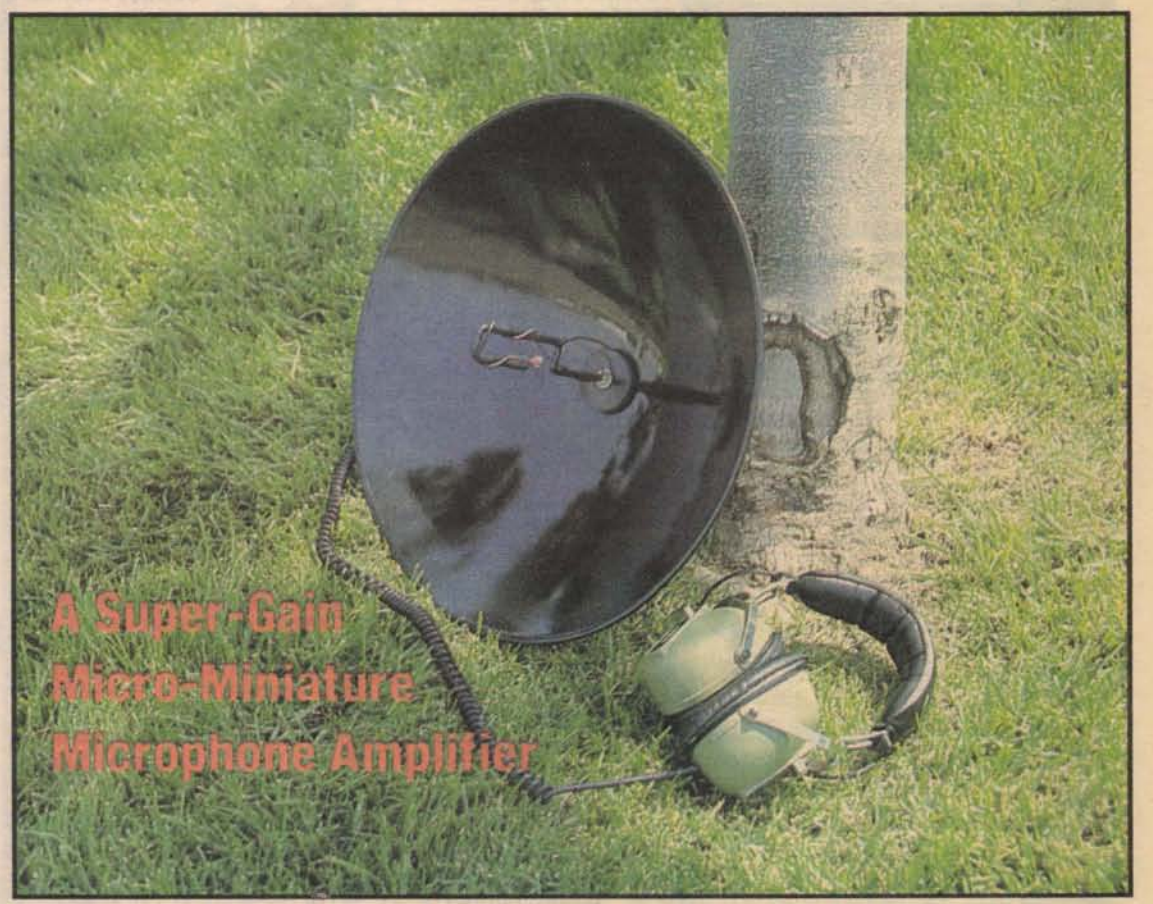
Build The DETECTOR '700

by Anthony Charlton



Have you ever wished for a device to greatly increase the hearing power of the human ear? Perhaps you are a Nature lover who likes to listen to birds chirp and insects buzz about. Or maybe you're a mechanic who's searching for a way to better diagnose what's wrong with engines by listening to them. Perhaps your job is more serious like finding dangerous leaks in gas pipelines. Regardless of whether you want to use a microphone for fun, profit or safety we have an inexpensive and powerful circuit here that you can build for only $15. In the process you'll learn about high-gain amplifier circuits, automatic level control, a few of the joys and a couple of the headaches the author experienced while designing this project.

CIRCUIT DESCRIPTION

The Detector '700 uses an Electret Condensor Microphone (ECM) cartridge as its sound sensor. (Please refer to Figure 1.) This particular ECM has a frequency response of 20 to 12,000 Hz which fits in nicely with human hearing range. The lower end of this spectrum is necessarily de-emphasized. Since the amplification factor is so great (with voltage gain of 47,000 times), energetic sound waves at low frequencies tend to "swamp" out the amplifier. For example: I was surprised to discover vibrations from passing vehicles and people walking on a wooden floor swamped the quiet sounds I was attempting to hear. So a simple *high pass filter* consisting of low-value electrolytic capacitors was devised. Since these are used in series with the microphone and the amplifier stages, their property called *capacitive reactance* allows higher frequencies to easily pass through. Lower pitch sounds are impeded or blocked altogether.

Returning to the ECM, the type used has a tiny built-in Field Effect Transistor (FET) which pre-amplifies the signal from the ECM element, and also lowers the output resistance from the ECM. Thankfully, that resistance is adjusted to a level suitable for connecting directly to a high-gain circuit without having to contend with impedance-matching techniques. Resistor R1 provides the needed current, which is called *Bias*, to the FET. Another good property of the ECM is its high *signal-to-noise ratio*. This means there is relatively little internal noise generated, so that the amplifier will hear more of the sound we want to amplify and less component-generated static. By carefully observing the output of the circuit on an oscilloscope whose gain is turned way up, you can see this internal noise as a line of random-frequency fuzz with occasional spikes appearing from nowhere. It sounds like a faint "hiss." The hiss is called *white noise* and the spikes are *popcorn noise* so named for their audible resemblance to popping corn. Fortunately, the noise level is small, and even a soft whisper emerges from and overcomes it readily. Note on the schematic capacitors C1, C6, C8 and C10. These are required for two reasons: #1 is to prevent unwanted oscillations from starting up – a plague of all high-gain amplifier circuits (as a fellow once said sarcastically: "If you want an oscillator, build an amplifier!). The #2 reason is to shunt ultrasonic energy – which we can't hear anyway – to ground, so it won't swamp out what we can hear.

A special IC was chosen to do the amplification. The LM387N Low Noise Dual Preamplifier gives a combination of low internal noise and high gain, low cost, easy availability, and will run off one 9V battery. As its name implies, it's a dual amplifier in a single 8-pin case which makes the job of attaching an Automatic Level Control (ALC) circuit much easier. Thus, we can use one amp in this chip to form the ALC, and the other as a high-gain mike amp.

The first stage of the LM387N is used as a inverting low-distortion amplifier. Its voltage gain is set by the ratio of resistors R3/R2 and as shown is 47,000. Now that's amplification! In some cases, it can be too much. But we trim loud signals to a comfortable level with the ALC next described. Also note metal film resistors are used for R1 and R2 since they generate less internal noise. I suggest using a metal-film resistor for R3 if you can find one of that high a value (4.7 Meg-Ohms) but I couldn't so I had to settle for a carbon-film type, which still works fine.

Stage 2 is what keeps loud noises from blowing your ears clean off! It's easy to understand if you think of how germanium diode D1 works. Let's say the output from Stage 1 is on the order of 0.3 volts as you are listening to something. Stage 2 normally has a voltage amplification factor of 1, which of course, is related to the ratio R6/R4. So at the 0.3 volt level and less, Stage 2 just inverts the signal and passes it on to Stage 3. Stage 2 also "buffers" the output from Stage 1; isolating it to prevent annoying problems of oscillation. But along comes a high-level sound. As soon as the output from Stage 1 (and hence Stage 2) exceeds 0.3 volts, germanium diode D1 which has previously been inactive, begins to conduct. As it does, the signal is fed back to the amp's input thru resistor R5. The louder the sound, the more signal will be fed back. Ultimately, the pair D1/R5 acts to instantaneously (well, not *instantaneously*, but in say, 10 millionths of a second) reduce the gain of Stage 2 from 1 to 1/15th. So no matter how loud the signal, it can not get bigger than 0.3 volts. This is a level that still is a little loud, but it won't hurt your ears. Silicon diodes like 1N4148 may be used for D1, but they will let louder sounds through before beginning to conduct due to their higher conduction voltage of about 0.6 volt vs. 0.3 volt for germanium. Finally, the large electrolytic capacitor C9 is used to filter the power supply. Without that large a value, the LM387N will break into a "shutdown" oscillation every time it hears a loud sound, and so the circuit goes dead for a second or two. I can't explain this, but it is an idiosyncracy of the LM387N that manifests in this circuit.

Stage 3 is a common-collector transistor amplifier. Its purpose is to provide enough current for the low-impedance headphones that are attached. In this circuit, Q1 current-amplifies with as little distortion as possible. Resistors R8 and R9 bias the transistor properly for this effect. Like with the other electrolytic capacitors used in the amp portion of the circuit, C7 is a fairly small value so it preferentially passes higher frequency sounds.

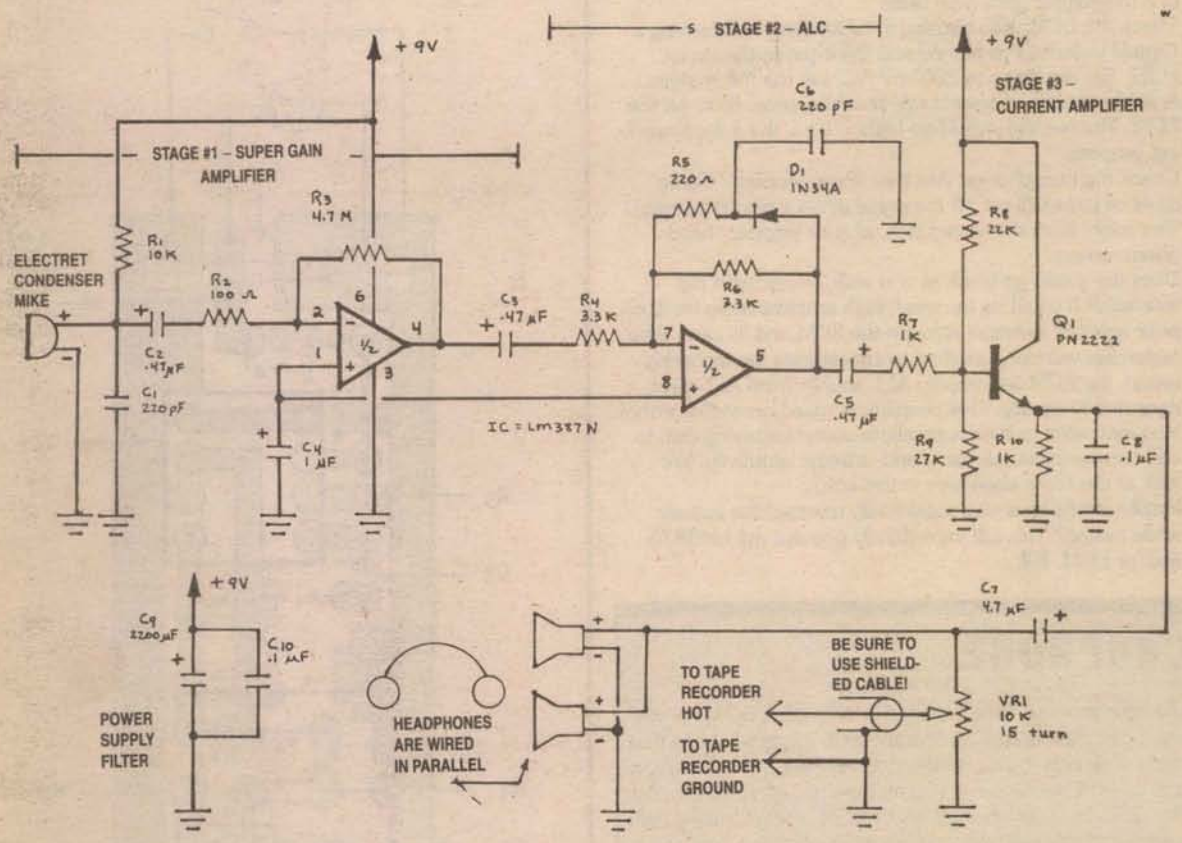
BUILDING THE CIRCUIT

It is suggested you follow the parts layout given in our miniature PC board pattern. A component placement guide is given too. One thing you must not do is try and breadboard this circuit! It's gain is so high that oscillation will undoubtably develop which will frustrate you. Note the thick traces on the sides of the CAD layout. They function as a "ground plane" to further reduce oscillation possibility, so you can see oscillation is important to avoid, yes?

Follow the recommended assembly procedure for best results. Since this circuit is rather small, try and obtain "miniature" components (which the hole spacing is calculated for), especially the electrolytic capacitors. Capacitors should be of fairly tight tolerance. ± 20% is suggested. (See "Parts List".) Since space is tight, you may have to "dry-fit" the components before soldering them in place so they will go together. *Remember to observe proper polarity with the diode, IC and electrolytic capacitors.* Pin #1 of IC 1 is uppermost *right* on the *foil* pattern, and uppermost *left* on the *component placement diagram*. It is further identified by the square-looking pad on both diagrams. This IC also has a dot on its case where pin #1 is. The ECM has a green paint dye on its ground side. If that's missing, hold the mike pin side up with the two pins at the top. The semicircle with the two notches has the (+) pin and the semicircle with one notch has the ground pin. Keep all component leads short while assembling.

1) If needed, clean the PC board with a fine grade of steel wool, and remove *all* wool flakes by brushing or blowing off. Note the board will have to be tapped on a table to get the wool out of some of the holes.
2) Install the IC socket and solder in place.
3) Install diode D1 and solder in place.
4) Install transistor Q1 and solder in place.
5) Install the resistors standing upright, and solder in place.
6) Install all capacitors except C9 and solder in place.
7) Strip 3/4" of insulation from each end of the shielded cable. Carefully cut the braid as per Figure 2, and prepare each end as shown. Attach the braid to the ground of the circuit board and the ground pin of the ECM. **Caution:** The ECM can be blown out by a static electricity charge. Use a grounded soldering iron and steps to minimize static if warranted. Solder the center conductor of the wire to the PC board and the ECM as shown.
8) Attach your headphone jack and plug. Match the jack type to whatever headphone plug you plan to use. It should be wired so that both speaker elements in the headphone are connected to the Detector–700's output in parallel, as

Figure 1 Schematic of Detector '700



shown on the schematic.

9) C9 is the largest component on the PC board. Determine whether your enclosure will fit the assembly with C9 standing up, or "hanging" off the back of the PC board. Install C9 accordingly. Note you will have two left-over holes on the board. These are for attaching a tape recorder adapter. Refer to "Improvements" for its implementation.

10) Install the LM387N in its socket. Connect up the power switch and battery clip.

11) Now to test the circuit! First, carefully check the board for cold solder joints and solder bridges. Connect up a fresh alkaline 9 volt battery to the battery clip. Plug in your headphones. Do not put them on yet. Arrange the ECM so it is away from the headphones, and turn on the power. You should not hear anything yet. Approach the headphones with the ECM. At some point, about 2' away, a feedback whine will be heard which diminishes and changes pitch as you pull away the ECM. Put on the headphones. Now you should hear your surroundings – but greatly amplified. WOW! If you whisper gently towards the mike from two feet away and can hear it, all is well.

Try doing some fun experiments like listening to the bubbler in your fish tank, or the ticking of an old-style clock. My wood

Back View

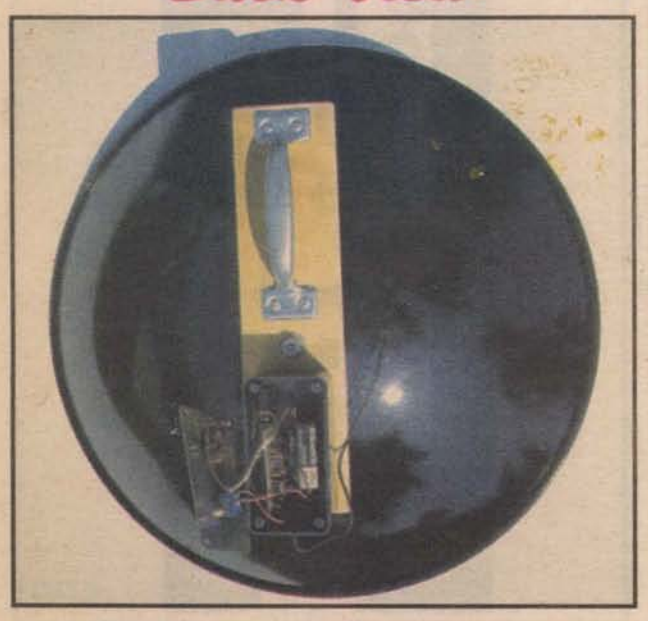


Figure 2

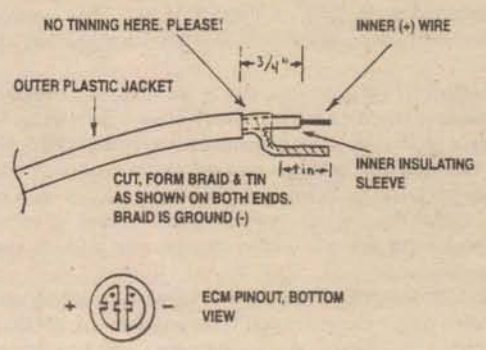
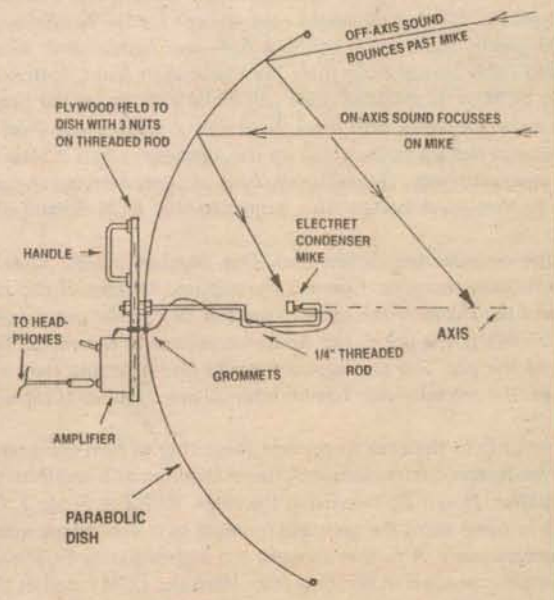


Figure 3



PARTS LIST

All resistors are 1/8 watt, 5% carbon-film unless otherwise indicated.

R1	10,000-ohm, 1/4 Watt, 1% Metal Film
R2	100-Ohm, 1/4 Watt, 1% Metal Film
R3	4.7 Meg-Ohms
R4	3,300-ohm
R5	220-ohm
R6	3,300-ohm
R7	1,000-ohm
R8	22,000-ohm
R9	27,000-ohm
R10	1,000-ohm

All electrolytic capacitors are "miniature" type. Voltages other than given may be used, provided they are above 10 WVDC.

C1	220 pF, ceramic disc
C2	.47 uF, 50 V electrolytic
C3	.47 uF, 50 V electrolytic
C4	1 uF, 50 V electrolytic
C5	.47 uF, 50 V electrolytic
C6	220 pF, ceramic disc
C7	4.7 uF, 16 V electrolytic
C8	.1 uF, ceramic disc
C9	2200 uF, 10 V electrolytic
C10	.1 uF, ceramic disc

Additional Parts:

D1	1N34, 1N60 or similar germanium diode
ECM1	electret condensor microphone cartridge, Digi-Key #P9949 or equiv.
Q1	PN2222, NPN transistor
IC1	LM387N, dual pre-amp IC in 8-pin case
8 pin	IC socket
1	9-volt battery snap

Miscellaneous Parts:

1	9-volt, alkaline battery
1	case
S1	optional push-on/off or snap switch
1	8-ohm, full-cover headphones
J1	headphone jack
VR1	10,000-ohm, 15-turn potentiometer (optional for Tape Recorder input)

A mini-PC board and kit of all miniature size electronic and "Additional Parts" (minus list of "Miscellaneous Parts") is available from ALLEGRO ELECTRONIC SYSTEMS, Dept. NV–1, 3 Mine Mountain Road, Cornwall Bridge, CT 06754 for $15 plus $3 shipping & handling; order #DET-700-PC. Free catalogs w/order. C.O.D. orders: (203) 672-0123.

ECM's, miniature capacitors, resistors and other parts related to this project: DIGI-KEY CORPORATION, 701 Brooks Ave. South, P.O. Box 677, Thief River Falls, MN 56701-0677 (800)-344-4539. Free catalog.

Parabolic dishes: EDMUND SCIENTIFIC COMPANY, 101 East Gloucester Pike Barrington, NJ 08007-1380 (609)-573-6250. A catalog charge may apply.

JUST HOW GOOD IS THE ALC?

To demonstrate the ALC's effectiveness I devised a test. First I used a pair of snug full-cover headphones. Then I loaded up a large blackpowder pistol (these make a terrible KA-BOOM!). Turning on the Detector-700, I first let my ears adapt to the gentle sounds of Nature coming through. Aiming at a tree stump, the pistol was touched off. The ALC worked perfectly, and I was not blasted by the resulting sound but in fact could hear its echo repeatedly bouncing off the hills. (Needless to say, we are located in a remote area, and I recommend less drastic test methods for your Detector 700!)

stove sounds like some sort of haunted inferno when the ECM "looks" at the flames; one hears the whump-whump of the flame and the crackling, sizzling and popping of burning wood sounds very dramatic (do experiments like this from a safe distance, of course). Pour some milk on a bowl of Rice Crispies for real excitement! Bet you never thought walking on a gravel driveway could sound like this ... After you experiment for quite awhile, the battery will run down. Note your battery has to be charged above 8 volts, or the circuit won't work properly. Fortunately, the circuit draws only about 20 mA, so a 9 volt Alkaline battery will last about 12 hours of continuous use before wearing out. An alternative and ultimately much cheaper power source is a true 9 volt Ni-Cad rechargeable battery. Make sure you get a true 9 volt type – most "9 volt" Ni-Cads are actually 7.2 volts, and work poorly with the circuit. Check advertisers in Nuts and Volts for Ni-Cad batteries.

TROUBLESHOOTING

If the circuit fails to work, try these steps to find the problem.

1) Did you breadboard the circuit? Remember its gain is too high to function on a breadboard.
2) Check battery integrity. Replace with a new 9 volt Alkaline type if needed. Power supplies won't work with this project due to their small amounts of ripple and since they often pick up stray 60 Hz AC from your surroundings.
3) Check the orientation of each component. Is their polarity correct?
4) Check again for "cold" solder joints and solder bridges. Use of a magnifying glass here helps.
5) Check the ECM. You can see if it's working by attaching a *Digital* Voltmeter at ground and the input to the circuit at R1. Set the range to 200 mV AC. Let the meter settle. A stable reading of several mV should appear. Blow on the ECM. The reading should go higher. If so, the mike is working properly.
6) Check the headphones. Are they wired properly? Some types of jacks will cut off the signal when a plug is inserted. You might have the wrong jack, plug or incorrect head phone wiring.
7) Does the sound go blank as you walk around with the assembly? It could be the wind, high ambient noise level, or poor acoustic isolation between the ECM and its case. Also, remember without a method to concentrate the incoming sound, the ECM will amplify ALL sounds from ALL directions nearly equally. This property is called *omnidirectional*. You may want to build a parabolic sound-gathering dish to add narrow-angle selectivity and extreme sensitivity. We look at this topic elsewhere in this article.
8) Finally, might have you accidentally reversed the battery while testing? This will immediately pop out the LM387N and/or ECM. **NV**

PARABOLIC MICROPHONE

The ultimate in sound-gathering ability can be had with a parabolic dish pick-up. This principle is also used by radio telescopes that listen to weak electromagnetic signals given off by distant celestial objects. A "parabola" is a special shape that concentrates all the sound energy (or more accurately whatever type of energy it was designed to receive) from its narrow geometric axis into a focus point. Off-axis sound simply bounces past the mike. Thus, if a dish had an area of 500 square inches (very roughly a 24" dish) and concentrated all the sound energy onto the .25" diameter opening of the ECM, theoretically a gain of 10,000 could be achieved over the mike by itself. Here, I am not taking into account effects of wave interference, frequency, and a half dozen mitigating factors, but let's just say a dish increases the sound pickup of the Detector '700 by an astounding amount! If you do a good job constructing the dish, expect to be able to hear distant bird chips or perhaps bugs buzzing around a far-away flower.

Figure 3 shows a sketch of a suggested design. You can use an aluminum parabola or perhaps even a Chinese wok which has close to a parabolic shape. Some people have used aluminum or plastic children's "flying saucer" sleds successfully. A 1/4" diameter threaded rod holds the plywood backboard to the dish. It is positioned through a hole drilled in the center of the dish and the plywood backboard. Use nuts and washers as needed to secure the assembly. Threaded rod may be bent quite easily using a large vise and hammer or heating it to red heat with a propane torch and using pliers or a vise to bend it. The electronics package and battery can be mounted in a small non-metallic enclosure attached to the plywood. Grommets are suggested where the shielded mike cable runs through the wood and dish.

Place the ECM as precisely as possible at the focus of the dish, and in-line with the geometric axis – and thus as close to center of what the dish will "hear" as possible. Your care here will determine how much gain the dish will have. Be sure and use ample acoustical insulation between the ECM and the support rod to prevent picking up sounds generated by handling the apparatus. I often use a little silicone RTV mixed with fiberglass insulation as that way you get both support and insulation. Perhaps you can think of a better idea. If unknown, the focal point of the dish may be found by pointing it directly at the sun on a clear day, and using a non-combustible item (say a penny) mounted on the rod. Adjust the rod length until the sun focuses sharpest on the item – that's your focal length. Beware of using anything combustible as a focus indicator as the concentrated infrared energy of the sun will quickly cause it to burst into flames.

Lightweight aluminum parabolas can be bought from Edmund Scientific Company (see Parts List). A suitable mounting can be fabbed from wood to make a tripod. You can also adapt the mount so it mates with a camera tripod. This enables easy continuous pickup of sounds originating from a specific location like, say, animals in their nests. Optionally, an inexpensive riflescope can be fitted to visually pinpoint the "target" you wish to eavesdrop upon. You could even get real fancy and add laser sighting to it!

IMPROVEMENTS

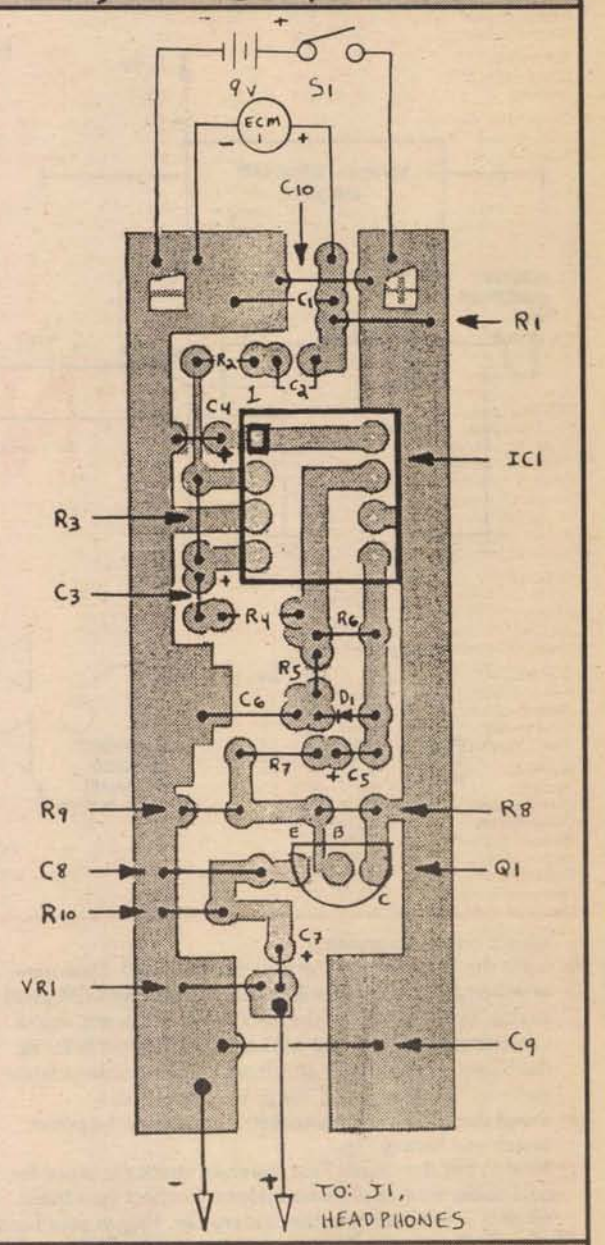
You can use virtually any type of non-metal case. Metal will pick up electrical fields, so avoid it. We made a very compact and unobtrusive prototype unit by putting all the parts in a plastic "C" cell flashlight case, except for the headphones which were full-cover 8 Ohm type. Your hearing power will greatly increase if you have full-cover headphones which block ambient noise. Carefully isolate the ECM, PCB and shielded cable acoustically from their case with foam, cotton or another soft material. Otherwise, every tap and scrape of the case, ECM or its shielded cable will make a thump in the headphones. Remember how high a gain this circuit has! We did have some problems with wind, however. A cover made from a few criss-crossed layers of plastic flyscreen cemented where the lens was helped by breaking up the airstream when it blew at the ECM. Similar to the screen used on regular microphones. Use ingenuity here. If your application requires carrying the circuit around and/or exposure to wind, your mike cover will have to be that much better. Also, remember the ECM doesn't like water.

An option is provided for attaching the Detector '700 to a tape recorder (see Schematic). This requires a 10K, 15-turn potentiometer, a length of shielded cable, and the proper jack to fit your recorder. Connect the top and bottom of the pot (Pins #1 and #3) to ground and the output pad respectively. Connect the shield of the cable to ground, and to the ground terminal of the recorder's jack. Next, connect the wiper (middle pin or #2) of the pot to the center conductor of the cable. The jack's hot terminal is connected to this also. By varying the level of the pot, you can experimentally find a setting that will enable recording the Detector '700's output. A word of caution here: the recorder also has an internal amplifier, so if the setting of the pot is too high, all you'll get is feedback whine.

To help conserve batteries, you might add a low-current flashing LED to the case to prevent forgetting to turn the power switch off. Check the data sheet for the LM3909N LED Flasher IC for typical circuits (available from Digi-Key at a small cost).

You can improve this circuit by stepping up the gain of the amplifier. How? By increasing the ratio R3/R2 in Stage 1. Or add some gain to Stage 2 by tinkering with the R6/R4 ratio. Expect at some point the gain will increase to a level where internally generated noise is substantial – or the circuit will oscillate spontaneously. A further thought is a higher-quality ECM that has less internal noise. This is specified by "Signal-to-Noise Ratio," and expressed in deciBels (dB). With the ECM listed in the Parts List it is greater than 40 dB. The more sensitive the ECM is the better, too. Again, this is expressed in dB, and for instance a -70 dB sensitivity is better than -64 dB.

Component Placement Diagram - Component Side



2x Lifesize Printed Circuit Board Pattern - Foil Side